A leap forward in DV over HF

The amateur radio high frequency (HF) bands are among the last hold-outs from digital voice (DV). That may finally change. Recent developments show that DV can outperform single sideband (SSB) over HF channels.

Introduction

The last major upgrade to HF voice technology occurred in the 1960s when SSB supplanted amplitude modulation (AM). Since then, almost every aspect of HF radio has gone digital except the air interface.

Digital displays and multi-function buttons have become common. Digital signal processors have been integrated with HF radios. Software-defined radio has replaced conventional radio architecture.

The migration of HF radio to DV will complete the process, unleashing better performance and new features.

Progress in DV has been achieved using machine-learning technology. A test was conducted between New South Wales, Australia, and Texas in the USA, (a 13,680km path) comparing DV with SSB. The transmitter power at both ends was 25W. DV was provided using FreeDV software with the Radio Autoencoder.

You can listen to audio clips from the test at [1]. The SSB signal is just readable: the audio is low and dips into the noise at times. The digital signal is much more readable and is easier on the listener's ears: the audio is generally loud and clear but there are a couple of brief moments when it becomes garbled. The DV signal is quiet, there is no atmospheric noise but there are some faint digital artefacts (whining sounds) heard during speech pauses.

While DV is widely used elsewhere, noise, weak signals and fading in the HF bands pose serious challenges.

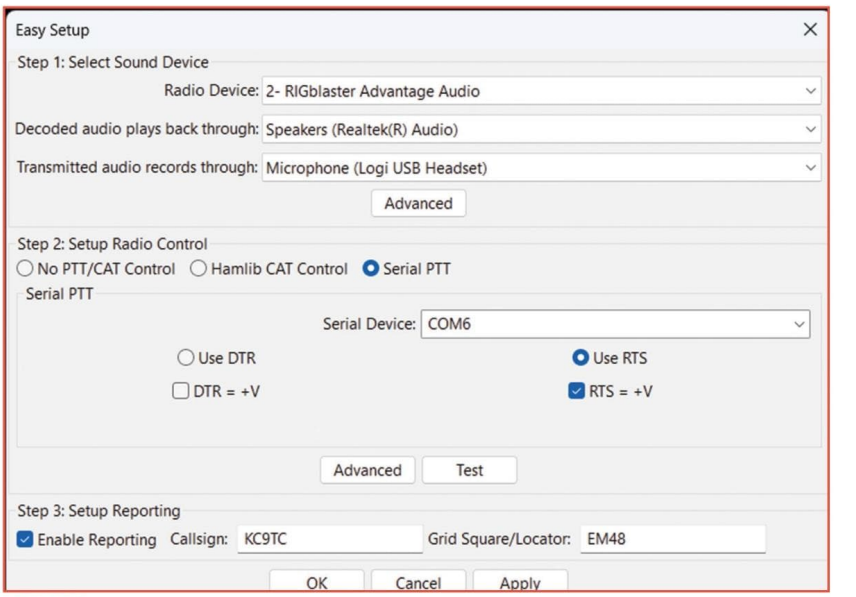

FIGURE 1: Use the 'Easy Setup' screen to choose your sound devices and radio-control method, test your push-to-talk method, and set your callsign and grid locator.

DV over HF: Some history

DV technologies, such as D-Star, System Fusion, and DMR, have been part of amateur radio for years. However, these systems were primarily designed for local communication over wide channels (spaced 15kHz apart) in the VHF/UHF bands [2].

The first in-depth article about DV over HF for amateur radio was by Charles Brain, G4GUO and Andy Talbot, G4JNT [3]. The authors developed special hardware to add DV to standard HF transceivers. Finding vocoders that would work over HF radio's 3kHz-wide channels was a challenge. Most vocoders, which convert voice to digital and digital back to voice, were designed for wider channels. In addition, most vocoders contained proprietary technology that could entail licensing fees. The authors' experimental hardware adapters cost about US$300 apiece to build. There were two breakthroughs in 2012. David Rowe, VK5DGR and David Witten, KD0EAG developed FreeDV, a free software program. FreeDV adds DV to an HF transceiver using a personal computer and a computer-to-radio interface. Many radio amateurs already had the PCs and interfaces. Rowe's development of an open-source vocoder (Codec 2), that worked over 3kHz channels, was the second breakthrough.

Anyone can use Codec 2 for free. The only other requirement is that any developer who modifies Codec 2 must share their modifications with the developer community.

Codec 2 is also used by the M17 project, primarily in the VHF and UHF bands [4]. In 2023, the Amateur Radio Digital Communications Foundation awarded the FreeDV project US$420,000 as a grant. The foundation said it hoped the grant would help make *"FreeDV performance superior to SSB over poor HF channels"* [5].

It didn't take long to bear fruit. The FreeDV project used machine learning to develop an entirely new system for sending speech over HF, called Radio Autoencoder (RADE). RADE was made available to users with the FreeDV-GUI application V2.0 for Windows 10 and above in mid-2025 [6].

More about DV over HF

DV has several advantages. DV signals are quiet, much like FM signals, because there is no atmospheric noise. The speaker's voice is loud and clear if the bits get through. The volume does not vary with transmitter power. DV may benefit from forward error correction (FEC). The receiver can correct bit errors provided the bit error rate isn't too high. However, RADE does not use FEC.

By using less bandwidth, DV signals can exploit greater spectral density to achieve a signal-to-noise ratio advantage over SSB. For instance, RADE requires about half as much bandwidth as SSB, giving it a 2dB to 8dB advantage over SSB under weak signal conditions. This is also why FT8, which uses only 50Hz of bandwidth, gets through when other modes can't. DV enables additional performance improvements and features.

Machine learning can be used to enhance performance beyond that which human designers could reasonably be expected to achieve. With a DV transmission, other information can be sent along with the voice such as the user's callsign, grid locator and name.

DV also has drawbacks. Digital signals suffer from the 'digital cliff' effect. While analogue signals degrade gradually, digital signals may suddenly

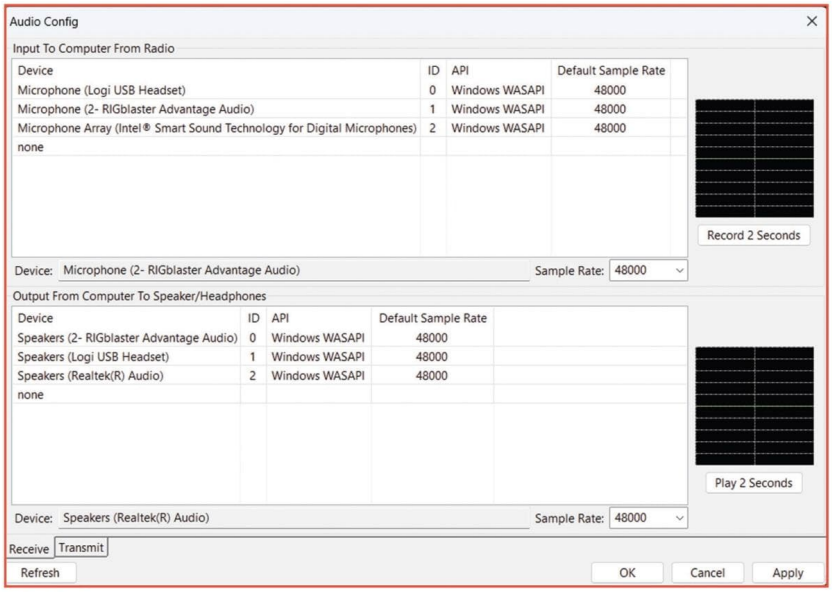

FIGURE 2: Use the 'Audio Configuration' screen to set up or change your receive devices.

disappear. For instance, many viewers of over-the-air television found that they could no longer receive TV stations that had less than perfect analogue signals after those stations upgraded to digital. DV may sound robotic. It's hard to recognise familiar speakers when that happens and most people find robotic-sounding voices annoying.

The use of DV over the HF bands poses particular challenges. Noise and fading can cause bit errors or lost bits. When propagation is good, HF channels may receive additional noise from distant lightning. DV consumes less bandwidth by concentrating on audio frequencies from 500Hz to 3kHz. But higher- and lower-frequency components are needed to ensure that voices are intelligible and natural sounding. These components must be reconstructed by the receiver.

Improving DV performance

Those old enough to remember the migration of cellular telephone from analogue to digital in the early 1990s may recall that speech quality was not always the best. That was despite having 10kHz or more bandwidth per voice channel.

Vocoders have improved dramatically since then. FreeDV's RADE achieved better performance over HF than previously possible by using machine learning. A large number of diverse voice samples were collected and sent under different simulated HF channel conditions. Machine learning was used to train the system, to home in on the best voice model.

This works because humans don't make different voice sounds at random. The next 'slice' of audio can often be predicted based on the current slice and the previous slice. Machine learning automates the process of trying different speech models until the optimal speech model is found.

The use of machine learning to develop more efficient voice encoding and decoding is not in itself new. Companies such as Facebook and Google, which serve large numbers of simultaneous users, have used this approach for some time. However, only RADE addresses the particular challenges of sending and receiving voice over narrow HF radio channels.

RADE focuses on encoding and decoding features of voice signals such as pitch, tone and volume. Instead of generating a bit stream like a conventional vocoder, RADE generates phase shift-keying signals used to construct the transmitted signal.

At the receiver, the 'FARGAN' machine learning-based codec (audio synthesiser) directly converts the received signal back to voice features.

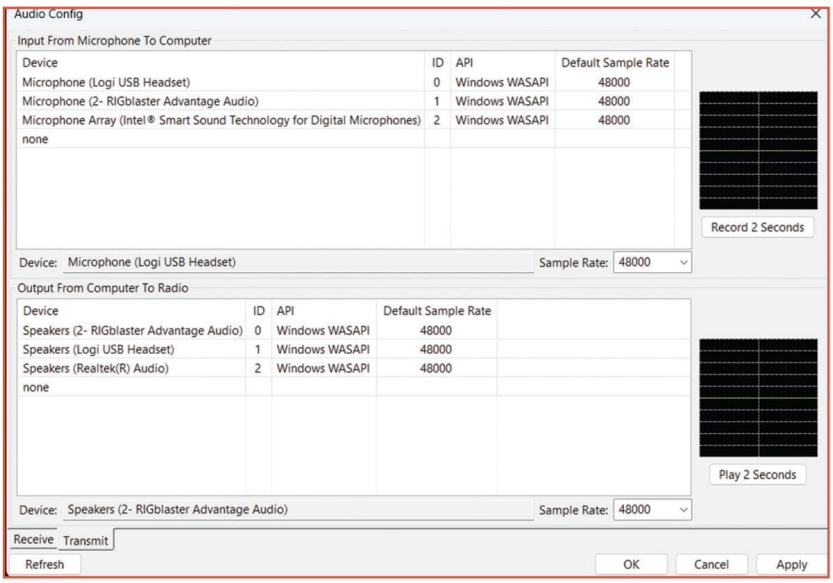

FIGURE 3: Use the 'Audio Configuration' screen to set up or change your transmit devices.

Installing and using FreeDV RADE

FreeDV with RADE is available on a demonstration basis in the FreeDV-GUI application V2.0 and above for Windows PCs or laptops. It runs on Windows 10 or later (64-bit environment). It is also available for Linux and MacOS.

If you are running data modes such as FT8 using a PC connected to an HF transceiver, you probably already have the hardware needed to start using FreeDV with RADE. However, the use of a headset or separate microphone is recommended over the use of a microphone built into a laptop or webcam, as these tend to pick up background noise.

The first time you start the FreeDV-GUI application V2.0 an 'Easy Setup' screen will appear. Select your radio's sound device, speaker and microphone, enter your callsign and grid locator and set up your computer control method (which may be as easy as selecting your radio model from the Hamlib drop down menu).

Use the 'Test' button to confirm that the software can key your radio (**Figure 1**). Be aware that DV has a duty cycle of 100%. Your radio transmits a continuous signal whenever it is keyed, whether or not you are speaking. Most transmitters need to be run at reduced power to protect the final transistors.

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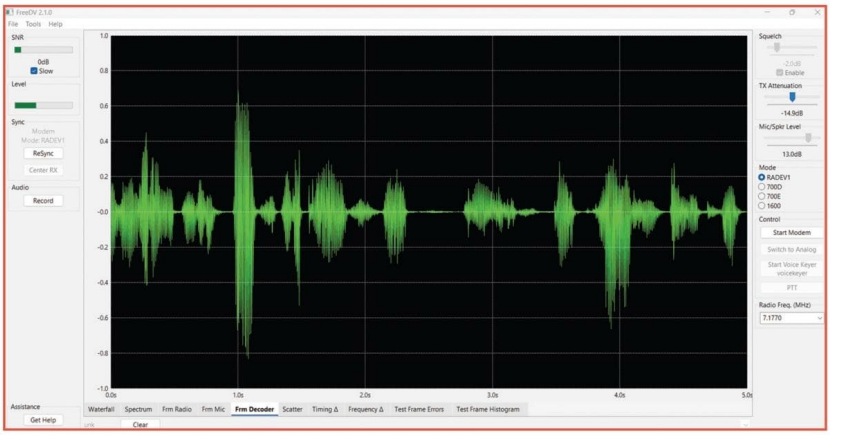


FIGURE 4: Set your drive, audio gain, and frequency on FreeDV's main screen. Press 'Start Modem' to receive and decode digital signals. Press PTT to transmit and press again to return to receive mode.

If 'Easy Setup' doesn't cover your set-up, click on the 'Advanced' button in the 'Easy Setup' window. Or, if you want to make changes later, select 'Audio Configuration' from the 'Tools' menu on the program's main screen.

Audio devices must be set up separately for receive and transmit. With 'Receive' selected at the bottom left of the pop-up screen, choose the device that sends audio from your radio to your computer at the top of the screen (your rig interface device) and below that choose the device you use to play the audio (eg speaker or headset).

You can test the audio playback device by pressing the 'Play 2 seconds' button at the right (**Figure 2**).

With 'Transmit' selected at the bottom left, select the microphone you will use at the top of the screen.

You can test the microphone with the 'Record 2 seconds' button at the right. You should see a waveform in the window above the record button as you speak. Then select the device that sends audio to your radio (the rig interface device) on the lower half of the screen (**Figure 3**).

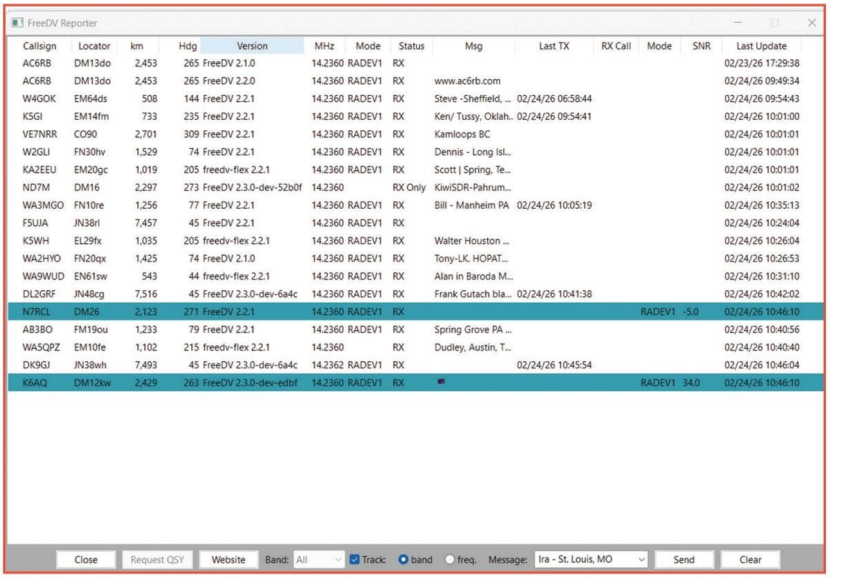
Refer to the FreeDV user manual for setting the drive and audio input levels on the program's main screen.

FreeDV follows the convention of using lower sideband below 10MHz and upper sideband above 10MHz. The one exception is the 60m band, which uses USB. DV for HF is treated as a telephony mode in the US so it may only be used in the phone bands and cannot be used in the 30m band. Other countries may treat it as a data mode.

When operating RADE or any of the other FreeDV modes, check first in analogue mode that the frequency is not in use. Then check again in digital mode. When operating in DV mode, be sure to identify your station as you would when using any other voice mode.

To operate FreeDV in RADE, first start the modem (**Figure 4**). Select the frequency from the drop-down menu (you may add frequencies to the list by selecting 'Options' and then 'Rig Control' under the Tools menu). You can see who else is currently receiving and transmitting by selecting 'FreeDV Reporter' under the 'Tools' menu (**Figure 5**).

Press PTT to transmit and press PTT again to go back to receive.



Callsign	Locator	km	Hdg	Version	MHz	Mode	Status	Msg	Last TX	RX Call	Mode	SNR	Last Update
AC6RB	DM13do	2,453	265	FreeDV 2.1.0	14.2360	RADEV1	RX						02/23/26 17:29:38
AC6RB	DM13do	2,453	265	FreeDV 2.2.0	14.2360	RADEV1	RX	www.ac6rb.com					02/24/26 09:49:34
W4GOK	EM64ds	508	144	FreeDV 2.2.1	14.2360	RADEV1	RX	Steve -Sheffield, ...	02/24/26 06:58:44				02/24/26 09:54:43
K5GI	EM14fm	733	235	FreeDV 2.2.1	14.2360	RADEV1	RX	Ken/ Tussy, Oklah..	02/24/26 09:54:41				02/24/26 10:01:00
VE7NRR	CO90	2,701	309	FreeDV 2.2.1	14.2360	RADEV1	RX	Kamloops BC					02/24/26 10:01:01
W2GLI	FN30hv	1,529	74	FreeDV 2.2.1	14.2360	RADEV1	RX	Dennis - Long Isl...					02/24/26 10:01:01
KA2EEU	EM20gc	1,019	205	freedv-flex 2.2.1	14.2360	RADEV1	RX	Scott | Spring, Te...					02/24/26 10:01:01
ND7M	DM16	2,297	273	FreeDV 2.3.0-dev-52b0f	14.2360		RX Only	KiwiSDR-Pahrum...					02/24/26 10:01:02
WA3MGO	FN10re	1,256	77	FreeDV 2.2.1	14.2360	RADEV1	RX	Bill - Manheim PA	02/24/26 10:05:19				02/24/26 10:35:13
F5UJA	JN38rl	7,457	45	FreeDV 2.2.1	14.2360	RADEV1	RX						02/24/26 10:24:04
K5WH	EL29fx	1,035	205	freedv-flex 2.2.1	14.2360	RADEV1	RX	Walter Houston ...					02/24/26 10:26:04
WA2HYO	FN20qx	1,425	74	FreeDV 2.1.0	14.2360	RADEV1	RX	Tony-LK. HOPAT...					02/24/26 10:26:53
WA9WUD	EN61sw	543	44	freedv-flex 2.2.1	14.2360	RADEV1	RX	Alan in Baroda M...					02/24/26 10:31:10
DL2GRF	JN48cg	7,516	45	FreeDV 2.3.0-dev-6a4c	14.2360	RADEV1	RX	Frank Gutach bla...	02/24/26 10:41:38				02/24/26 10:42:02
N7RCL	DM26	2,123	271	FreeDV 2.2.1	14.2360	RADEV1	RX				RADEV1	-5.0	02/24/26 10:46:10
AB3BO	FM19ou	1,233	79	FreeDV 2.2.1	14.2360	RADEV1	RX	Spring Grove PA ...					02/24/26 10:40:56
WA5QPZ	EM10fe	1,102	215	freedv-flex 2.2.1	14.2360		RX	Dudley, Austin, T...					02/24/26 10:40:40
DK9GJ	JN38wh	7,493	45	FreeDV 2.3.0-dev-6a4c	14.2362	RADEV1	RX		02/24/26 10:45:54				02/24/26 10:46:04
K6AQ	DM12kw	2,429	263	FreeDV 2.3.0-dev-edbf	14.2360	RADEV1	RX				RADEV1	34.0	02/24/26 10:46:10

Close | Request QSY | Website | Band: All | Track: band freq. | Message: Ira - St. Louis, MO | Send | Clear

FIGURE 5: FreeDV 'Reporter' shows you other active operators. Choose 'Website' at the bottom to open a web page showing activity on all bands.

The future

The migration to DV on the HF bands is inevitable. In part, this is because DV is more immune to noise, which is a growing problem. It's also because DV offers more opportunities for further performance improvements and new features. Today, there are several different, and mostly vendor-proprietary, DV solutions used in amateur radio. In the future, amateur radio will probably converge on a small number of open-source solutions.

DV performance will continue to improve. This will make weak signal and portable operation more enjoyable. Although this article focuses on the use of RADE in the HF bands, it can also be used for weak signal work in the VHF and UHF bands, as well as via geosynchronous satellites such as QO-100.

The widespread use of DV on HF will make websites such as PSK Reporter even more useful (PSK Reporter doesn't recognise SSB signals but it does recognise FreeDV). This will allow operators to assess propagation and it enables automatic notifications about band openings to specific regions or countries, even notifications when a friend is on the air and being heard by stations in your area.

FreeDV with RADE could be a big step toward multimedia over HF. There are already data chat modes that support sending avatars and pictures, actuating sounds and graphics at the receiving station and pointing the QSO partner to specific websites for additional content. Imagine, for example, pictures being sent during the pauses between speech.

References

[1] https://freedv.org/2024/10/
[2] There is some experimental use of D-Star on HF frequencies, but it consumes as much bandwidth as an AM signal (6kHz), uses a proprietary vocoder, and requires an Icom HF radio at each end.
[3] http://www.arrl.org/files/file/Technology/tis/info/pdf/0056x003.pdf
[4] 'The M17 Project', May, 2024 RadCom, RSGB
[5] https://www.ardc.net/apply/grants/2023-grants/enhancing-hf-digital-voice-with-freedv/
[6] https://freedv.org/download/